Resource Assessment/Accessibility

Marc Schwartz and Donna Heimiller
National Renewable Energy Laboratory
Golden, Colorado

Renewable Energy Modeling Series
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Resource Assessment Classification

- Large-Scale Spatial Data
  - Wind Resource Mapping
    - ♦ Quantify Available Windy Lands
- Temporal Variability
  - Diurnal
  - Seasonal
  - Yearly
  - Decadal
- Wind Forecasting
  - Individual Wind Farms
  - Aggregate Forecasts

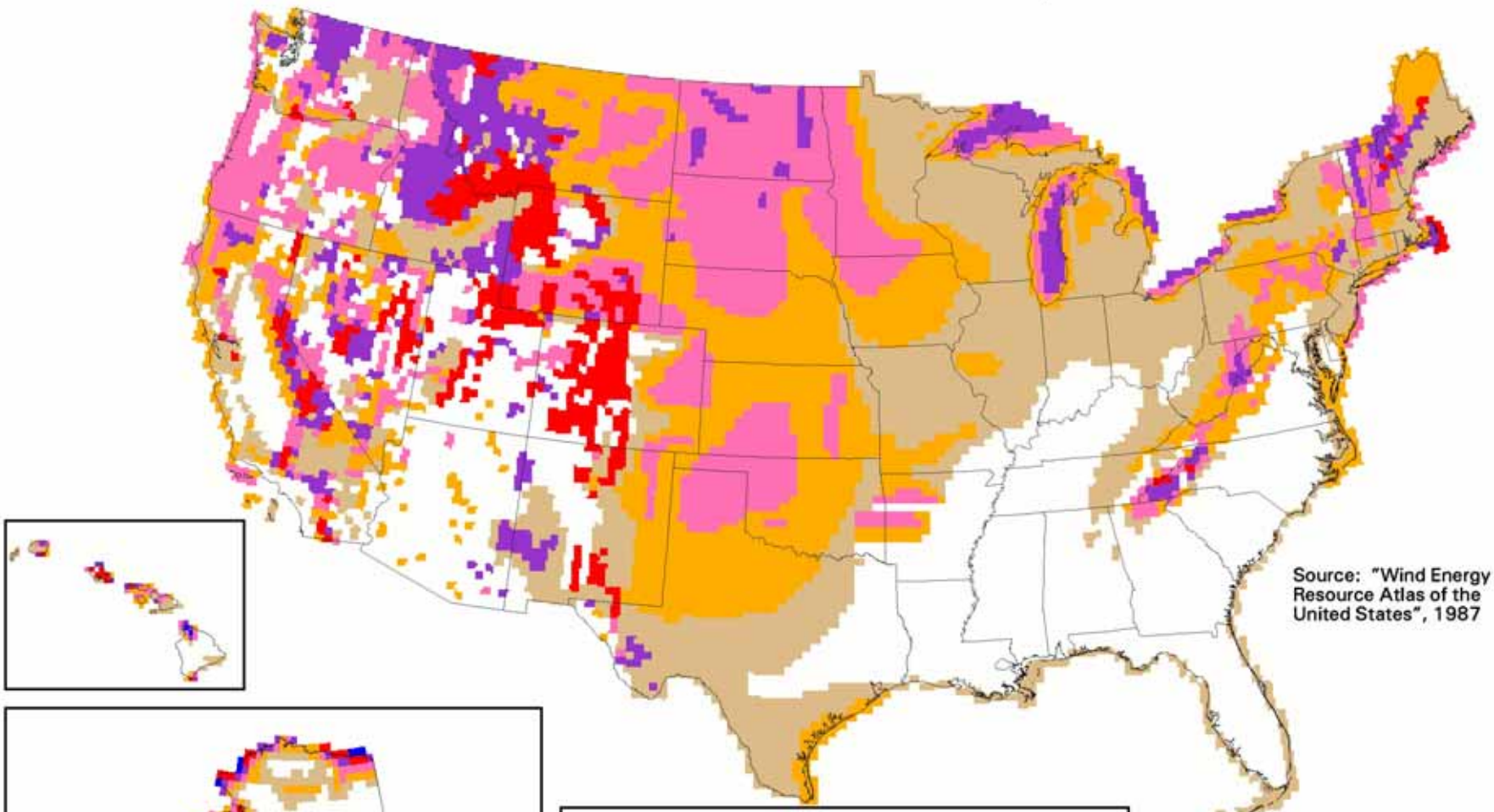
Standard Wind Resource Classification by NREL

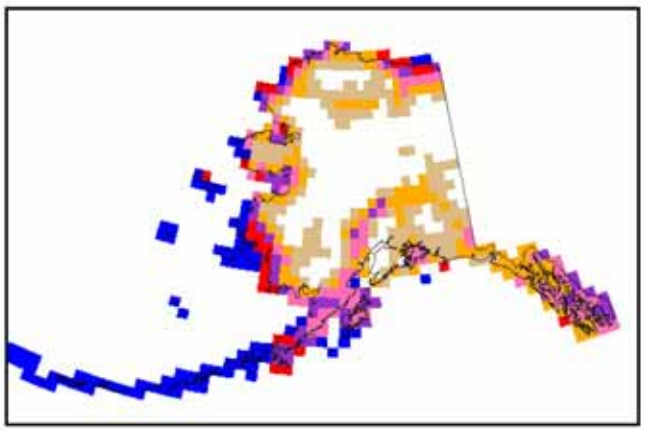
Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

United States - Wind Resource Map





Source: "Wind Energy Resource Atlas of the United States", 1987

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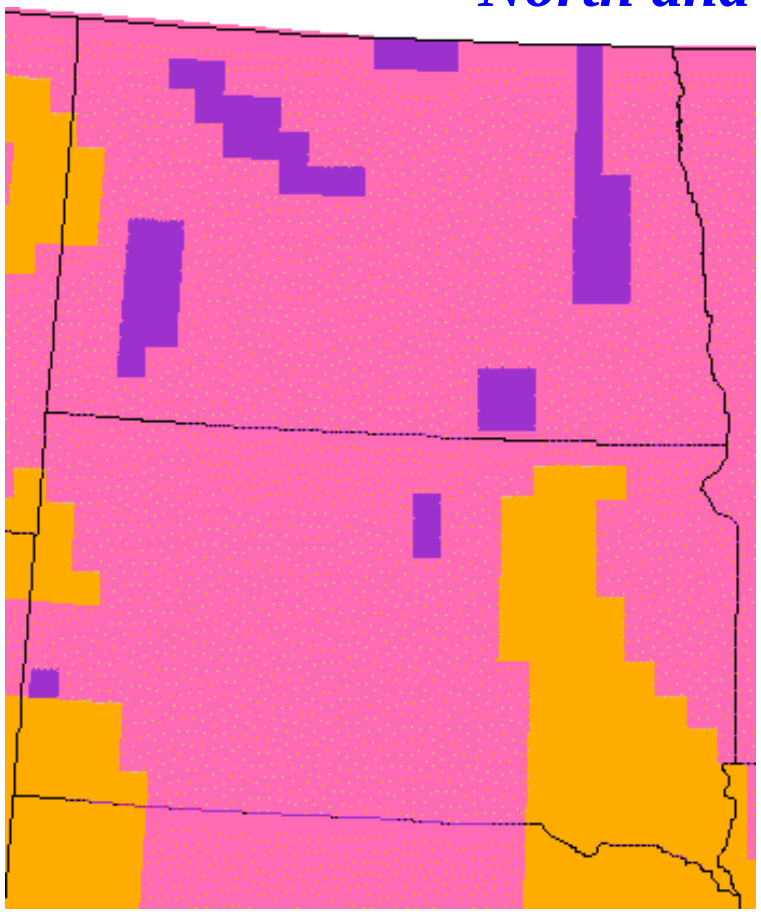
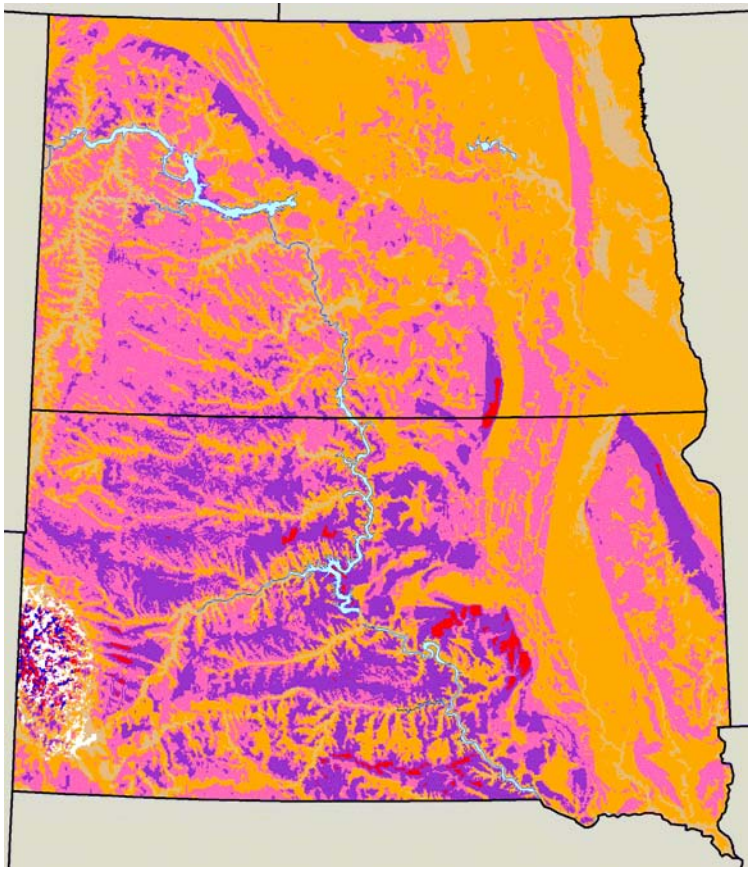
Why Re-Map the U.S. Wind Resource?

- Increased interest in wind energy development
  - U.S. Department of Energy's Wind Powering America activity
  - New state policies and funds available for renewable energy
  - Larger market for utility-scale and small wind turbines
    - ♦ Farm use and distributed generation
    - ♦ Need more detail than provided in 1987 Atlas
- Advanced mapping tools available
  - Better meteorological and topographic data sets
  - Increased utility of computer hardware and software

Comparison of Digital Wind Map from 1987 U.S. Wind Atlas and New (2000) High-Resolution (1-km^2) Wind Map North and South Dakota



1987



2000

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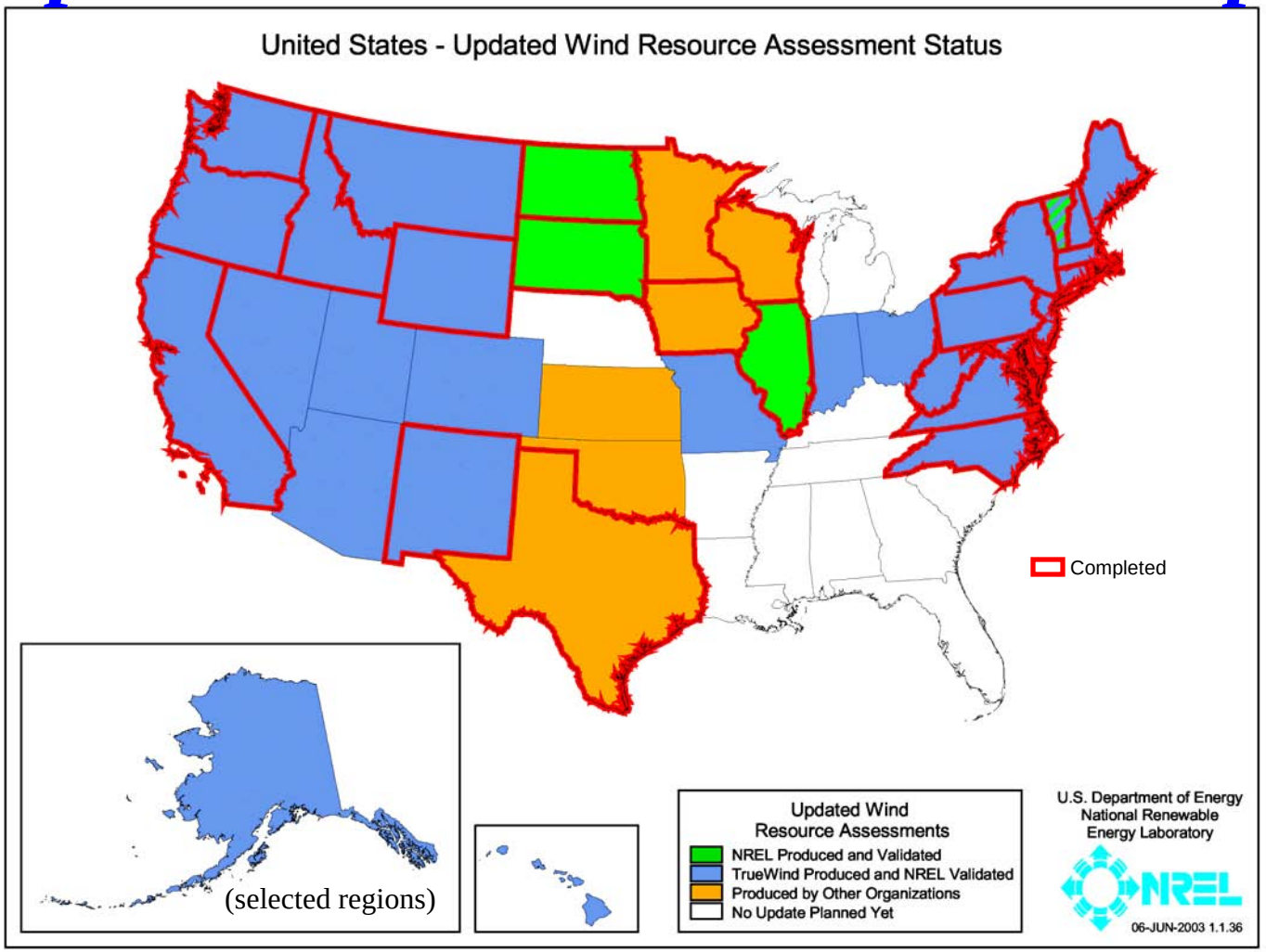
High-Resolution Wind Mapping Approach

- Produces 1 km^2 or finer resolution wind power maps
- Most states re-mapped either by NREL or TrueWind Solutions (TWS) under Wind Powering America
- Combination of numerical,(TWS) empirical and analytical methods (NREL mapping and validation)
- Updated maps are validated
  - NREL and consultants validate NREL and TWS produced maps
- Maps designed for regional wind mapping and not micrositing
- Does not depend on high-quality surface wind data

Updated State Wind Resource Maps



http://www.eren.doe.gov/windpoweringamerica/where_is_wind.html

Validation Process

- NREL produced a validation spreadsheet used by itself and consultants
  - Site coordinates and elevation
  - Measurement heights and period of record
  - Measured speed and power
  - Adjusted speed and power to map height
  - Map estimates for speed and power
  - Qualitative comments
- NREL & TWS reviewed validation results
- TWS adjusted preliminary maps based on quantitative and qualitative inputs

North Dakota Validation

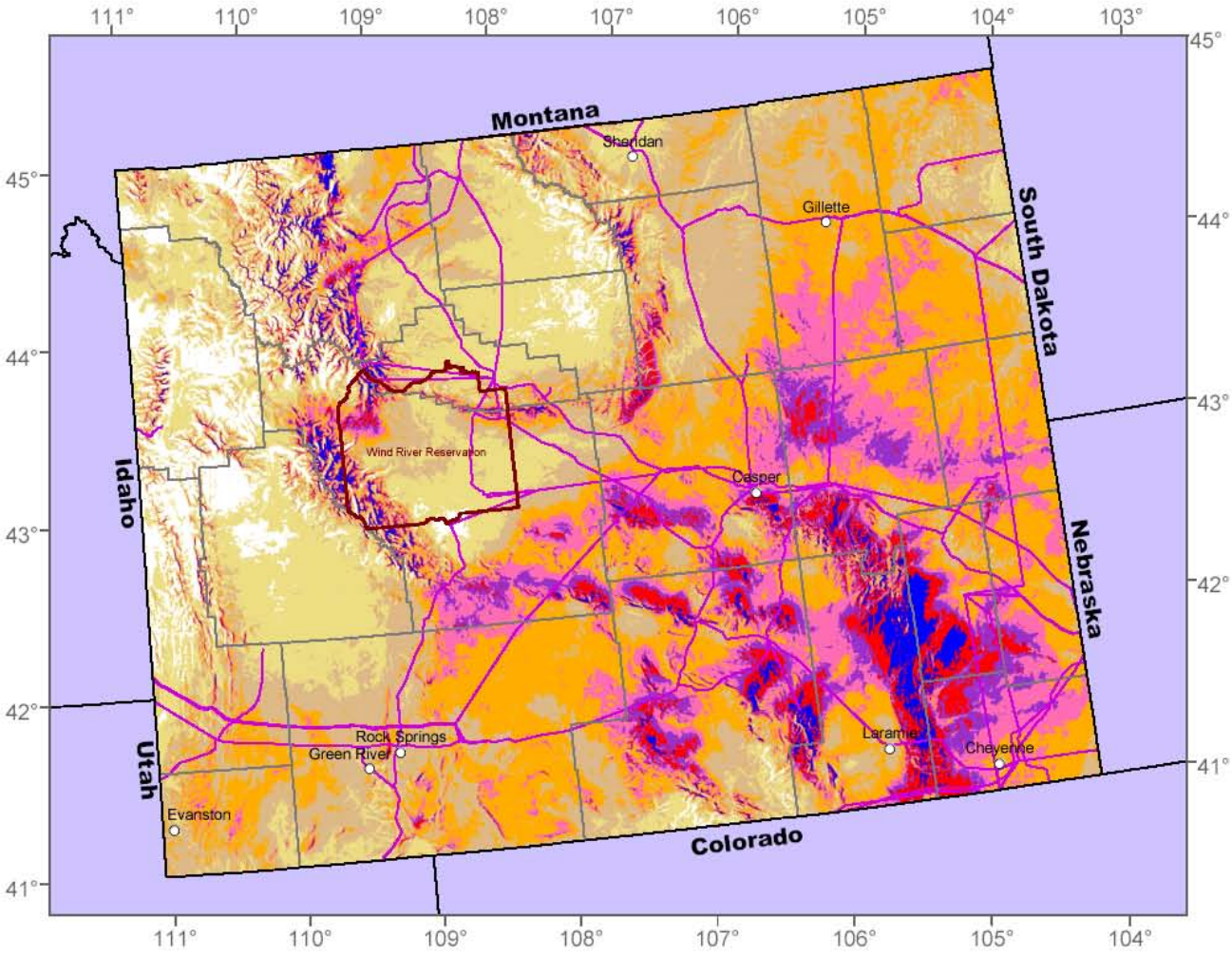
Station	Lon (W)	Lat (N)	Pred/Meas	Pred. Class	Meas. Class
Olga	99d 04m	48d 44m	1	4	4
Petersburg	98d 01m	47d 59m	0.81	3	4
Benedict	101d 06m	47d 53m	0.87	5	6
Ray	103d 12m	48d 16m	0.94	5	5
Green River	102d 56m	47d 04m	1.18	5	4
Wilton	100d 42m	47d 08m	0.89	4	5
Alfred	99d 01m	46d 35m	0.78	5	6

Wind power density estimates at 6 out of 7 locations are within 20% of measured values.

Updated U.S. Mapping Products

- Validated products
  - Annual average maps
    - ♦ Wind Power Density at 50-m height
    - ♦ Resolution either 1 km, 400 m, or 200 m
- Supplemental products from TWS (not validated)
  - Weibull k grids at 50 m - annual average
  - Seasonal grids of speed and power at 50 m
  - Diurnal grids of speed and power at 50 m
  - Wind roses at 50 m (10-km grid)

Wind Power Map of Wyoming at 50 m



Wind Resource at 50 m

Power Density Class	Wm2
1-	< 100
1+	100-200
2	200-300
3	300-400
4	400-500
5	500-600
6	600-800
7	> 800

Key to Features

- Counties
- Tribal Lands
- Transmission Lines

0 30 60 90 120 Miles

TrueWind Solutions

Projection: Universal Transverse Mercator (Zone 11)
Spatial Resolution of Wind Resource Data: 400 m

This map was created by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated with available surface data by the National Renewable Energy Laboratory. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.

Results of State Mapping

- Improved (over 1987) high-resolution wind resource maps
  - Base Class 4 and higher wind resource (sq. km) increased in some states and decreased in others
- Important technical issues better defined because of validation process/future research areas
  - Surface roughness
  - Stability
  - Low-level circulations

NREL's GIS Data

The NREL validated high-resolution wind power class data is available for download from: **http://www.nrel.gov/gis/index_of_gis.html**

- Pacific Northwest (ID, MT, OR, WA, WY)
- Mid-Atlantic (DE, MD, NC, NJ, PA, VA, WV)
- California, Illinois, North Dakota, South Dakota and Vermont

- Data from the 1987 *Wind Energy Resource Atlas of the United States* is also available for download

Available Windy Land - Background

- Original DOE/PNL windy land and wind electric potential calculation completed in 1991
  - Based on 1987 *Wind Energy Resource Atlas of the United States* 25 km by 25 km grid cell size
- Used environmental and land-use exclusions for each grid cell in a “moderate” land use scenario
- Reasons for modification to 1991 windy land/wind electric potential methodology:
  - Updated high-resolution (smaller grid cell size) wind resource maps
  - High-resolution GIS data sets
    - ♦ Terrain, Land Use, Land Cover

Quantifying Available Windy Lands (in Sq. Km) by DOE/NREL (2003)

- Class 4 and higher resource areas used as base
- Use updated state maps when completed by NREL and TWS
  - Use DOE/PNL maps for other states
    - ♦ No final decision has been made on using updated state maps completed by other organizations
- Input received from consultants via questionnaire
- Environmental Exclusions
- Land-use Exclusions
- Offshore resource not included at present

Environmental Exclusions

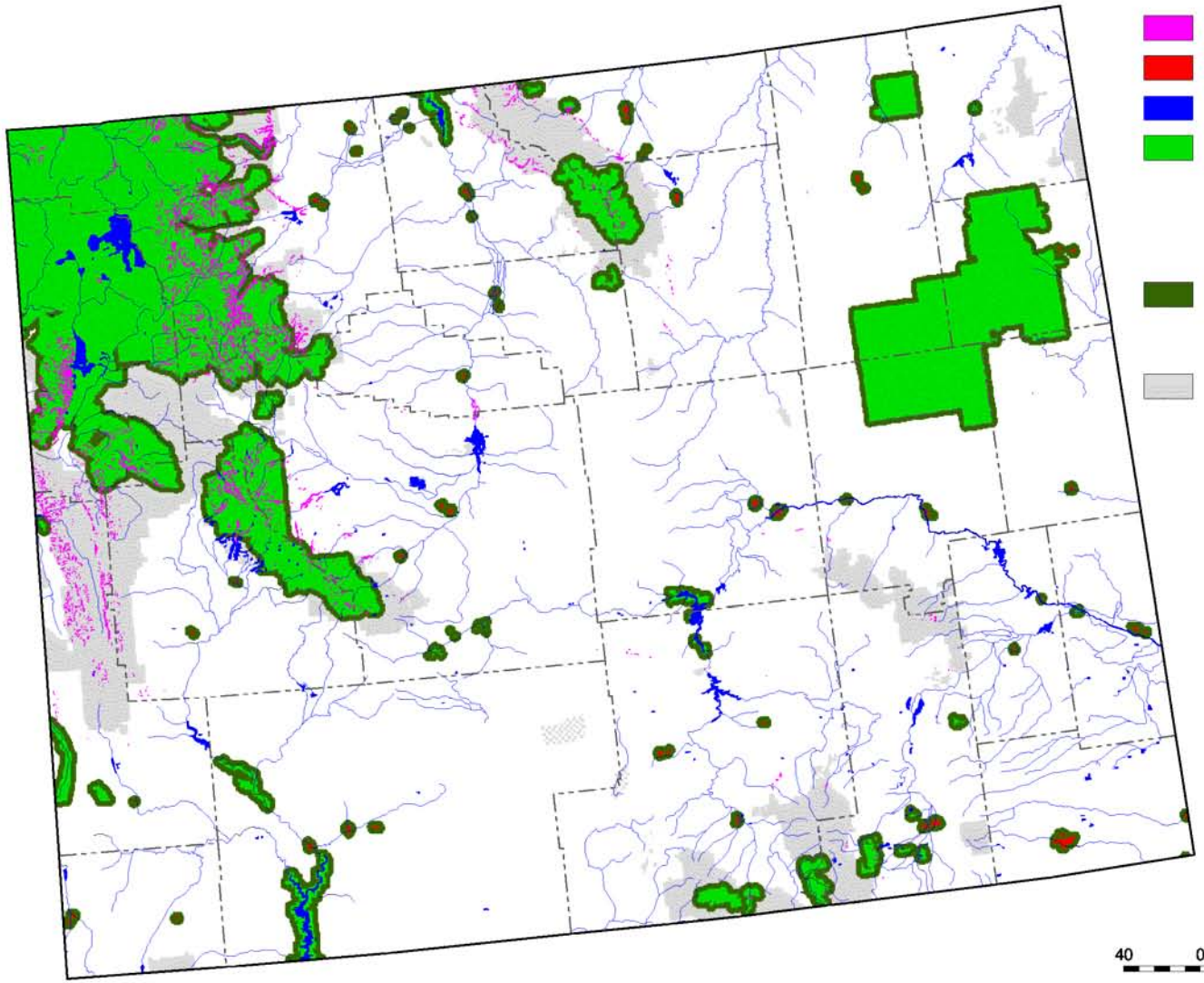
- 100% Exclusions
  - National Park Service, Fish and Wildlife Service, State and private environmental lands (where available in a GIS format)
  - Wildlife, Wilderness, and Recreation Areas on federal land
- 50% Exclusions
  - Remaining U.S. Forest Service and DOD lands
- 0% Exclusions
  - Bureau of Land Management lands

Land-Use Exclusions

- 100% Exclusions
  - Urban areas and airports
  - Wetlands
  - Water bodies
- 50% Exclusions
  - Non ridge crest forest
- 0% Exclusions
  - Ridge crest forest
  - Agriculture and range lands

Additional Windy Land Factors

- Slope Exclusions
  - Slopes greater than 20% excluded 100%
- 3 km buffer around airports and the 100% exclusion areas, large water bodies excepted
- Windy grid cell contiguity/density factor
- New methodology slightly less restrictive
- Distance from transmission lines not included in windy land calculations
- Windy land → electric potential
  - Direct conversion from sq. km to potential installed capacity (DOE/NREL)



Slope >= 20%

Urban or Airfield

Water

Environmental Exclusions
(Wilderness, parks, wildlife refuges, and any other federal land with a special designation, and GAP Land Stewardship status 1 lands)

3 Kilometer Exclusion Buffer
(for urban, airfield and environmental exclusions)

Lands excluded 50%
(U.S. Forest Service, U.S. Dept. of Defense, and GAP Land Stewardship Status 2 Lands)

40 0 40 80 120 160 Kilometers

25 0 25 50 75 100 Miles

Wyoming - Windy Land Exclusions

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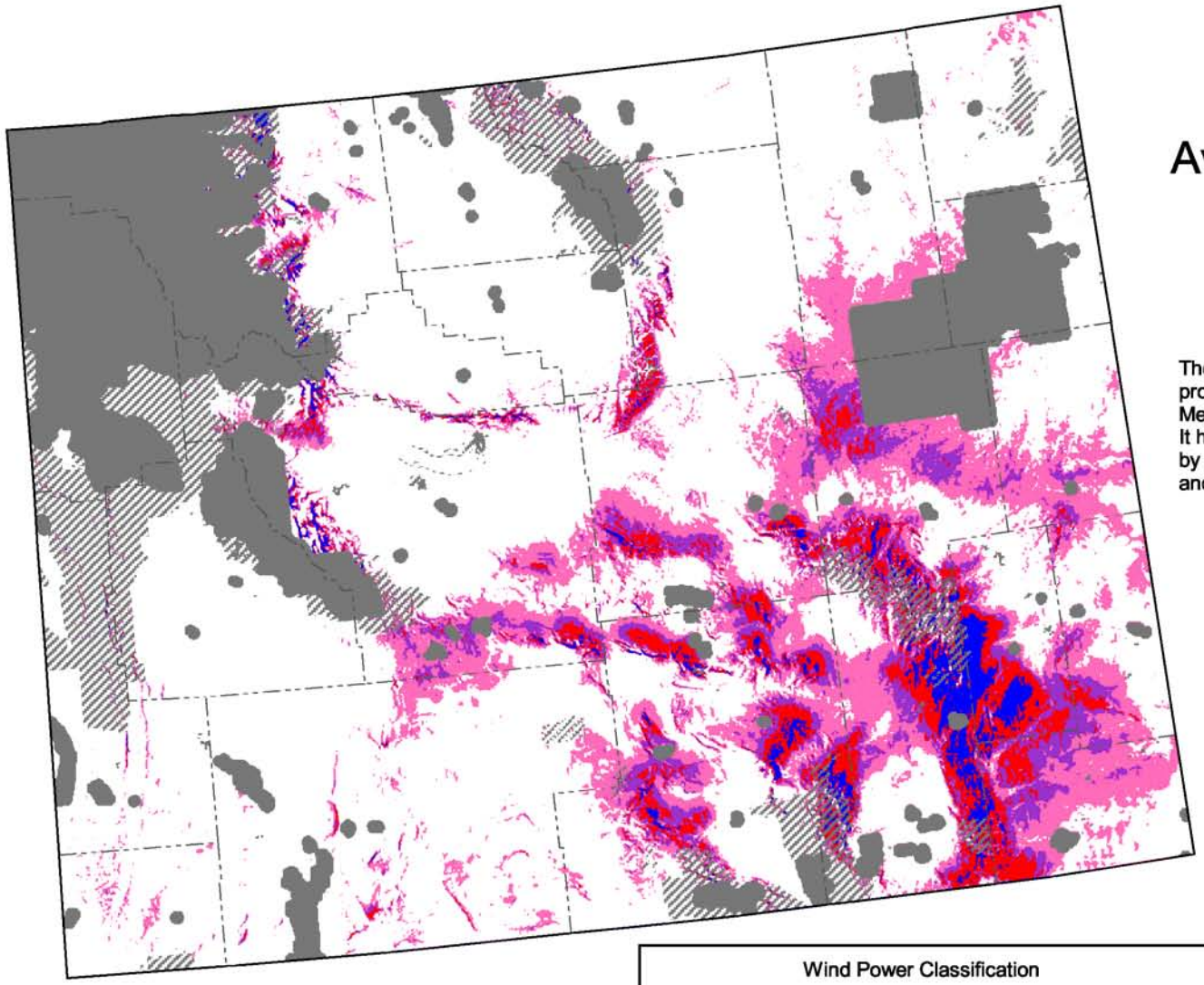

Wyoming

Available Windy Land (for utility-scale development)

The wind power resource data for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data. It has been validated with available surface data by the National Renewable Energy Laboratory and wind energy meteorological consultants.

100% Excluded Areas
50% Excluded Areas

40 0 40 80 120 160 Kilometers
25 0 25 50 75 100 Miles

Wind Power Classification

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[a] Wind speeds are approximate and based on a Weibull k value of 2.0

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Limitations of Windy Land Calculations

- Limitation of updated resource maps
- Windy lands based on 50 m wind power class
  - New turbines have hub-heights of 80+ m and 100 m hub-heights on the way
  - Simple wind speed and power extrapolation from 50 m to 100 m not accurate
  - Little high-quality data available from 100+ m

GIS-based Wind Modeling at NREL

- Renewable resource assessment and validation
- Wind electric potential assessment
  - State and regional updates of windy land
  - Update data used in NEMS
- Identification of high potential wind resource areas
  - BLM renewables assessment report
- Wind Powering America
  - Clean Power Estimator
- WinDS model data processing

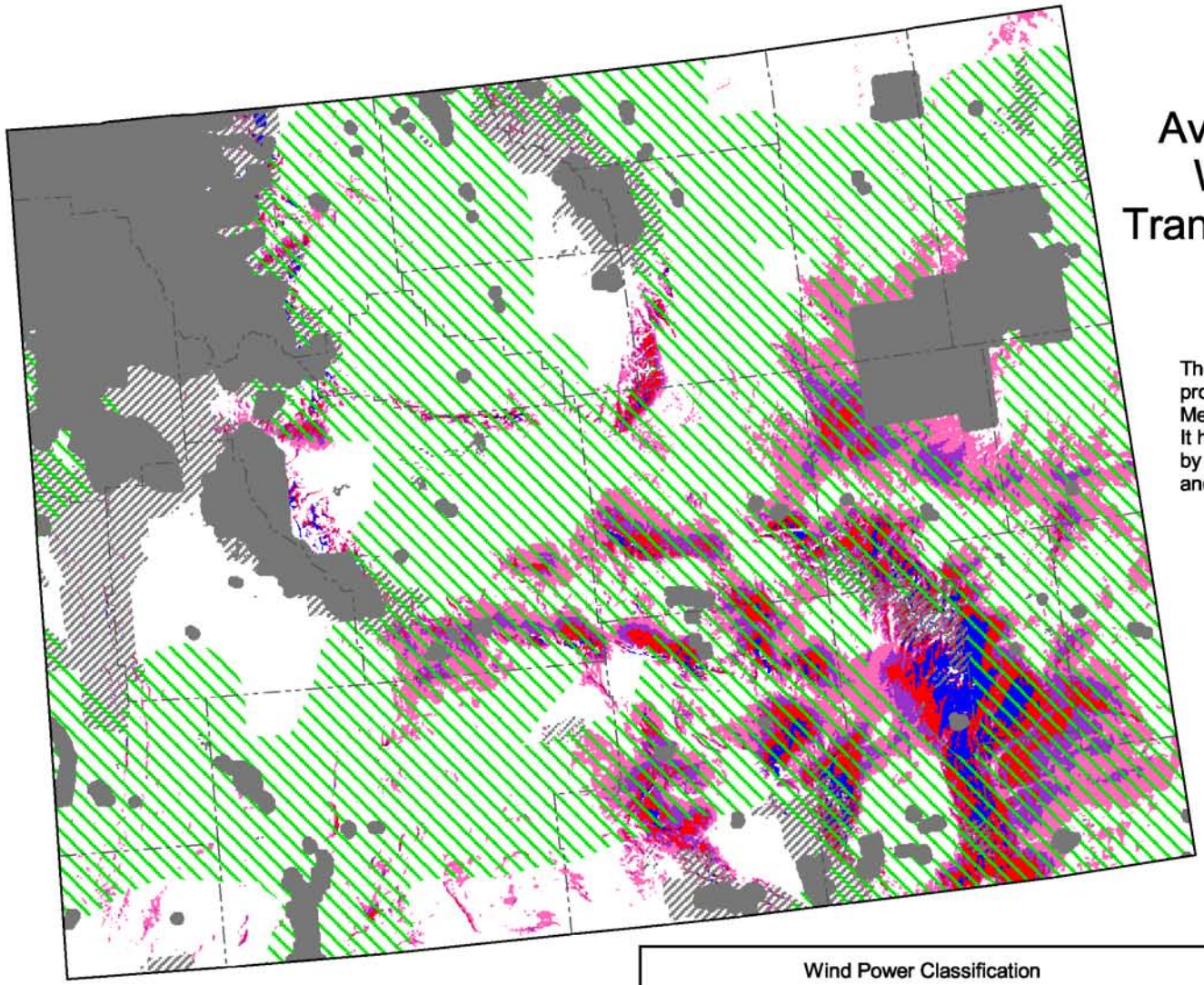
Update of Available Windy Land Input to NEMS

- NEMS currently uses the 1987 U.S. wind resource data, with resource limited by distance to transmission lines as described in a 1995 report by Parsons et. al. (*Estimates of Wind Resource Land Area and Power Potential in Close Proximity to Existing Transmission Lines*)
- EIA approached NREL to update this input to NEMS to reflect the new high-resolution wind data sets and more comprehensive transmission information currently available

Update of Available Windy Land Input to NEMS

- Analysis will utilize the exclusion criteria described earlier to quantify available wind land
- In addition, the resource will be limited to within 20 miles of transmission lines
- Final input file will have wind resource summarized by NEMS modeling region, power class, and distance to transmission lines (within 5, 10, and 20 miles)

NEMS Modeling Regions



Wyoming

Available Windy Land Within 20 Miles of Transmission 69 - 345 kV

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100% Excluded Areas
50% Excluded Areas

20 Mile Transmission Area

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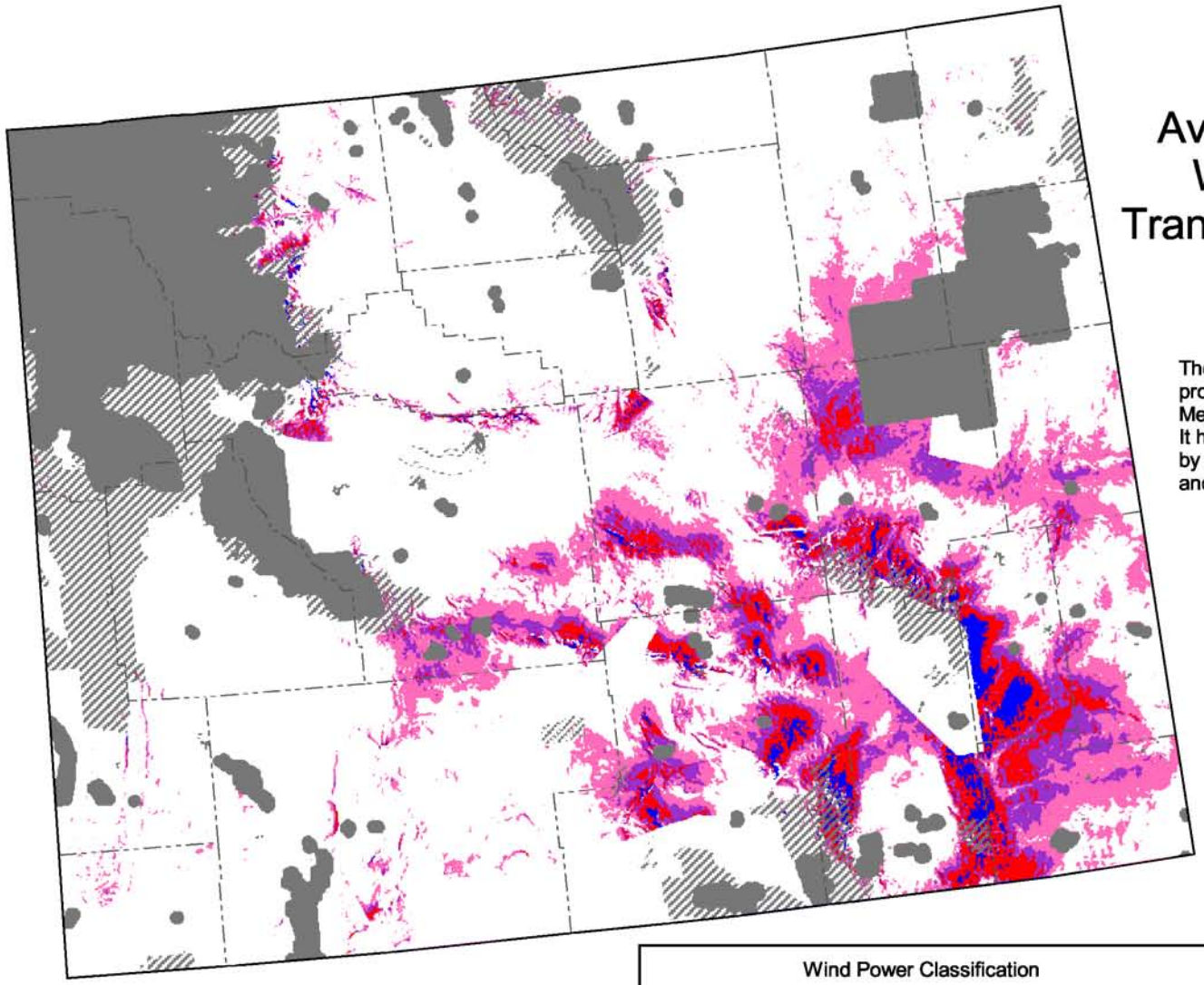
Wyoming

Available Windy Land Within 20 Miles of Transmission 69 - 345 kV



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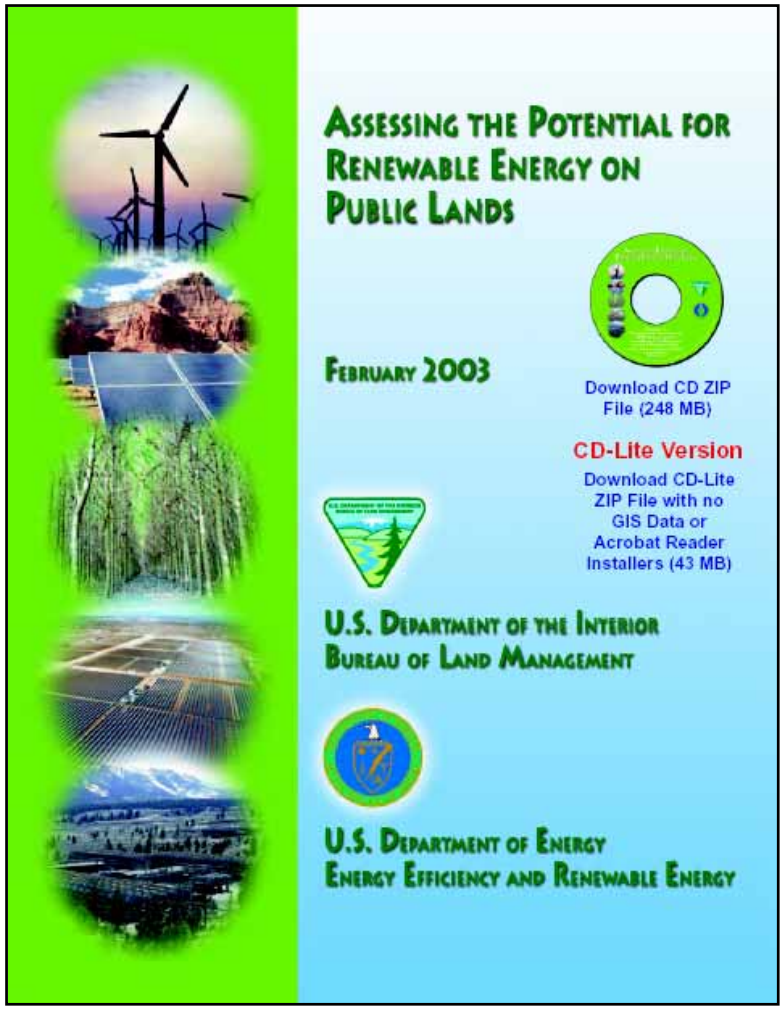
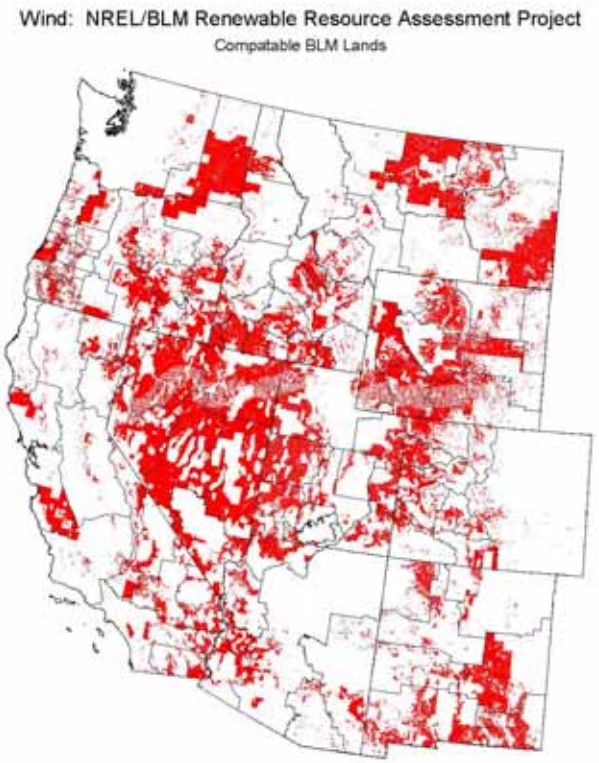
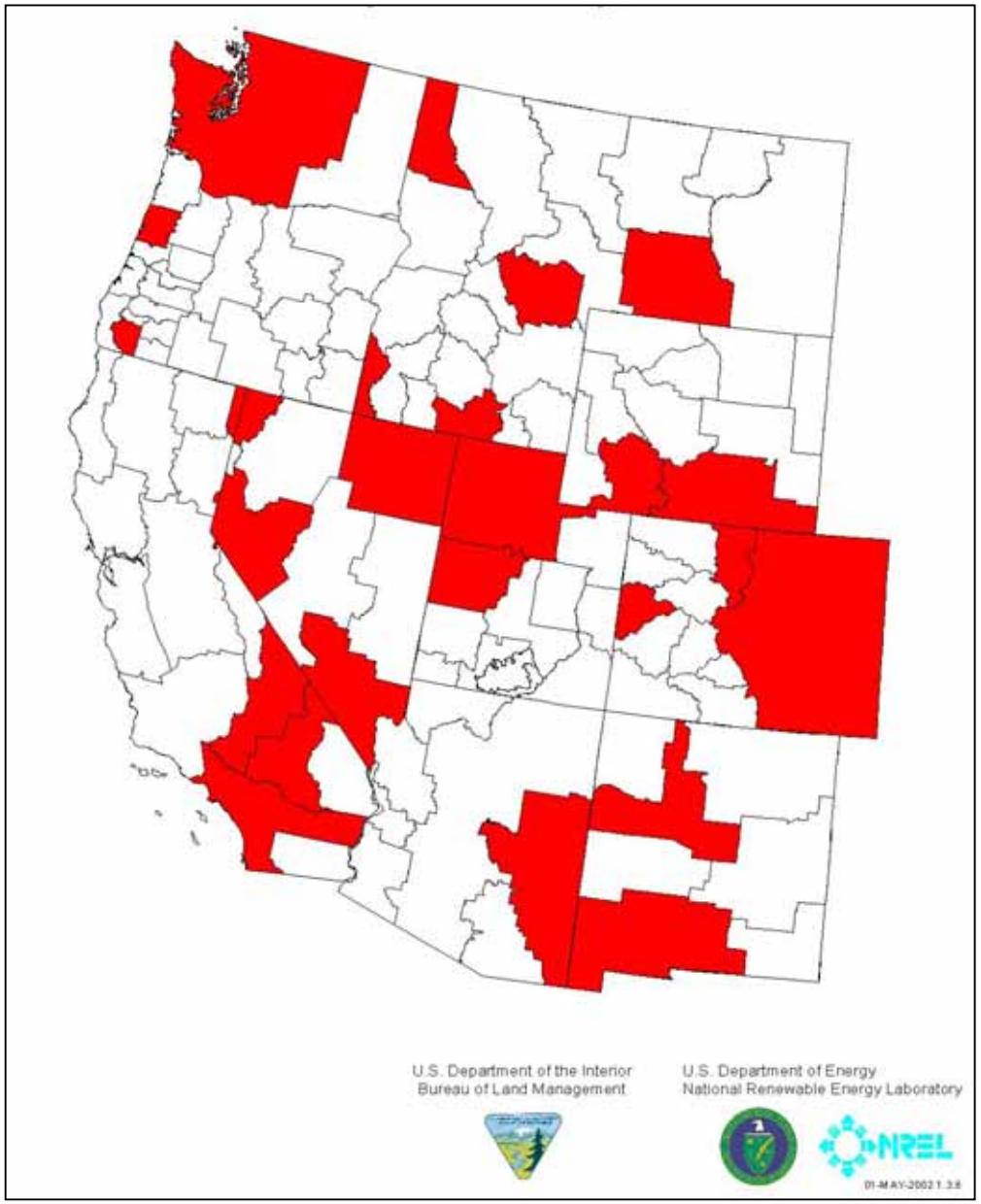
Renewable Energy Development on BLM Lands



- NEP called for increased access to energy resources on public lands
- Approached by BLM to identify planning units with developable renewable resource potential to prioritize those units that need to address renewables in their management plans
- Short time frame (2 months)
- Wind, PV, CSP, biomass and geothermal

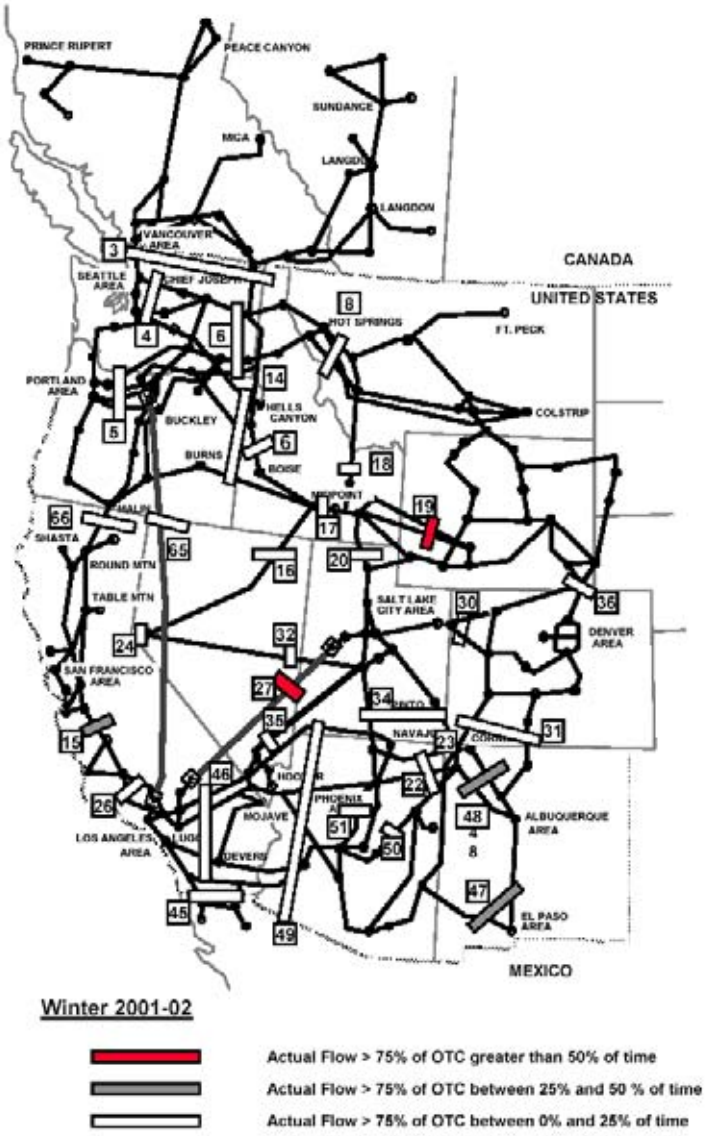


- Criteria for identifying areas with wind development potential:
  - Within 50 miles of a major road
  - Within 25 miles of transmission between 69 and 345 kV
  - Compatible BLM land (not a wilderness, wilderness study area, national monument or national conservation area)



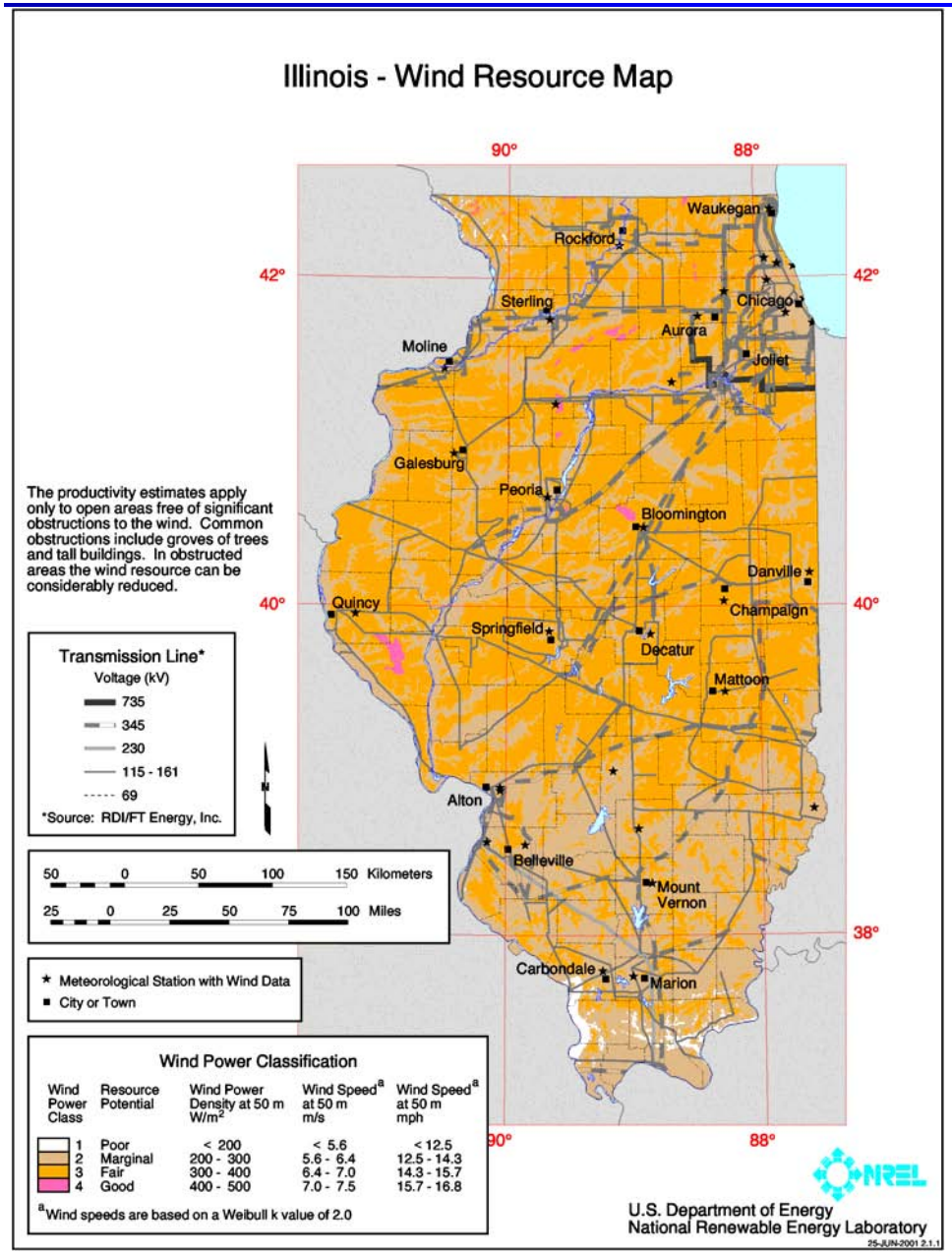
Final Results

- 25 BLM planning units were identified as having the highest potential for wind development
- Based on class 5 and better wind resource availability and proximity to major load centers or major transmission lines that connect to a major load center



Future Enhancements

- Transmission congestion
  - Draft Western Interconnect Transmission Path Flow Study
  - Some constrained path data available from Platts for the eastern United States, but does not have the same level of detail as the western interconnect
- May be used for many analysis projects

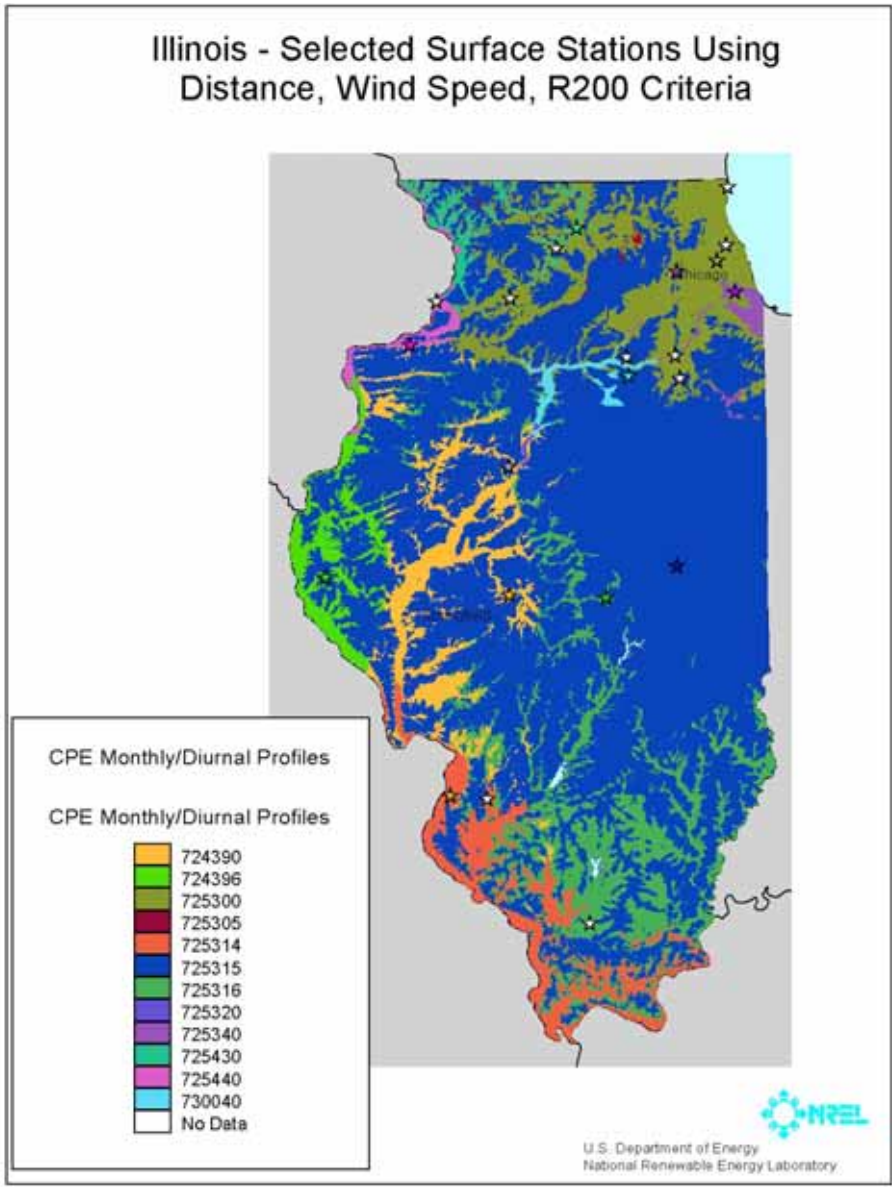


Clean Power Estimator

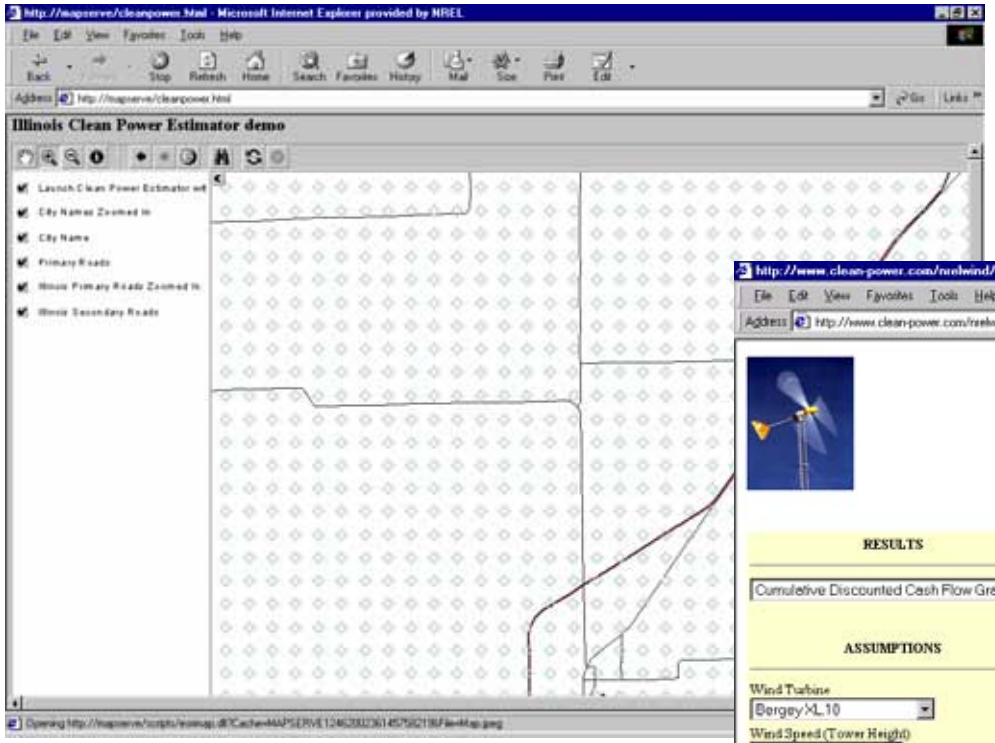
- Starts with high resolution annual wind power map
- Include analysis of daily and monthly wind speed patterns for meteorological stations in the surrounding area
- Need to be able to relate stations with good meteorological profiles to the grid cells

Chosen Station Profiles

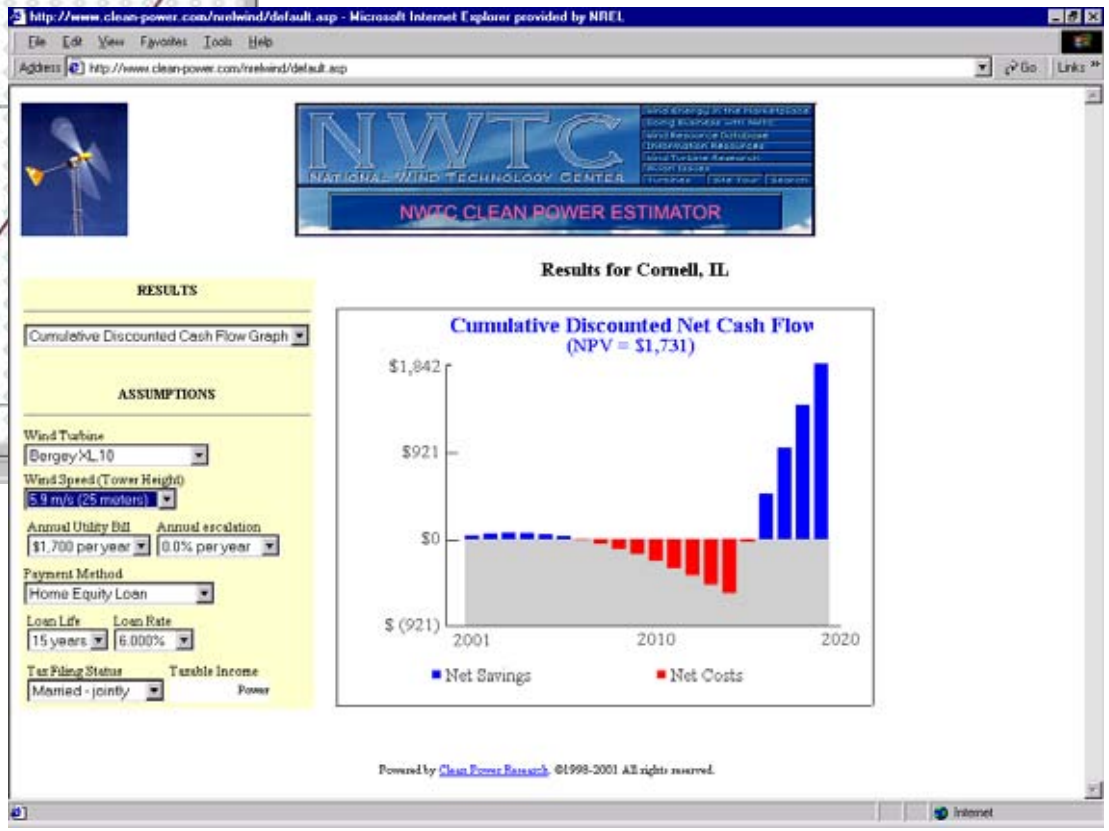
- Stations are assigned to each grid point by comparing the wind and terrain at the station with the wind and terrain at the grid point
- Choose the station that minimizes these differences:
  - Distance to station
  - R200 elevation
  - Wind speed at 10 m (30 m wind adjusted down to 10 m using 1/7th Power Law)



Clean Power Estimator for Wind



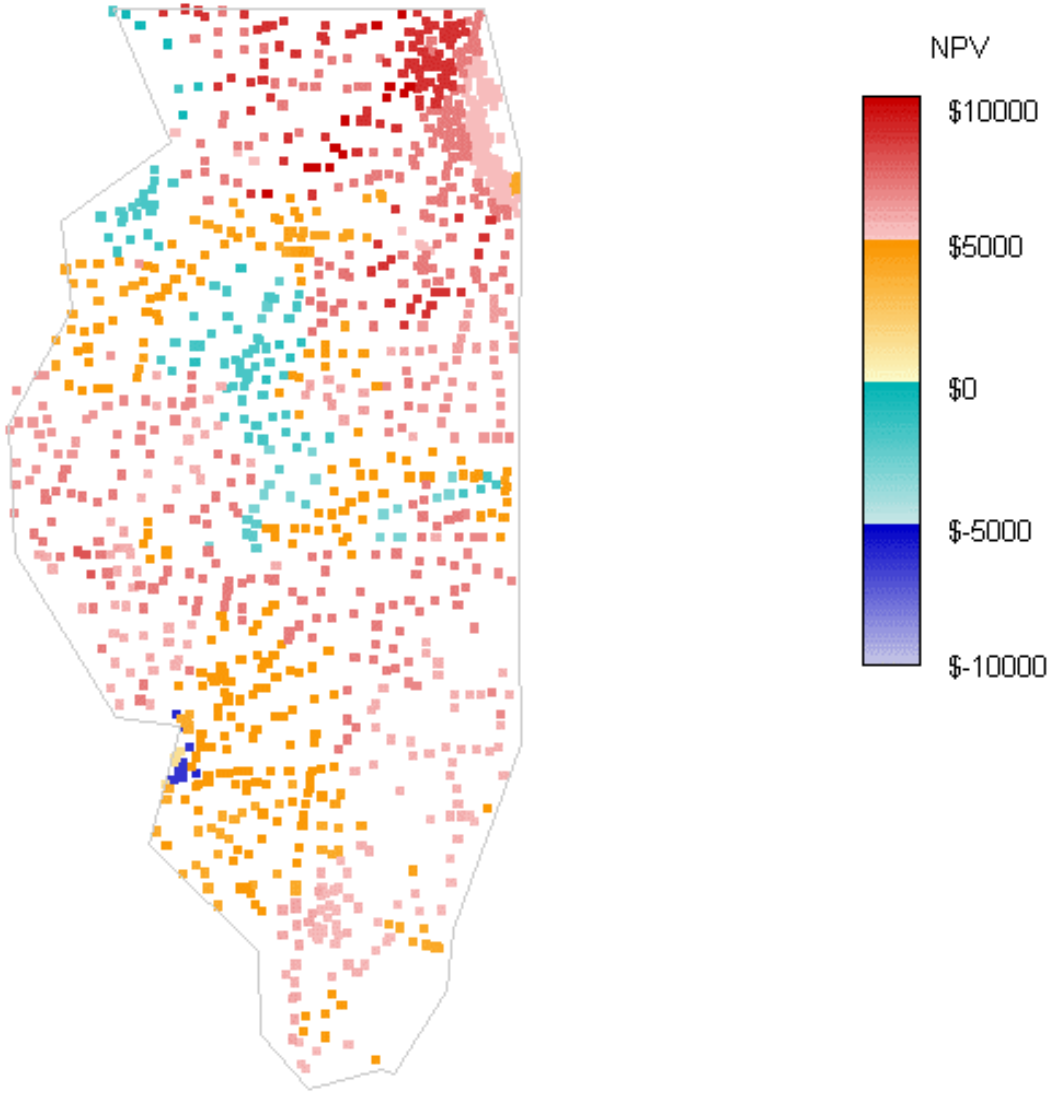
...Web point and click map server GUI, EQUALS ...



...Data for accurate estimation of wind turbine value under any utility rate scheme.

Net Present Value, Small Wind

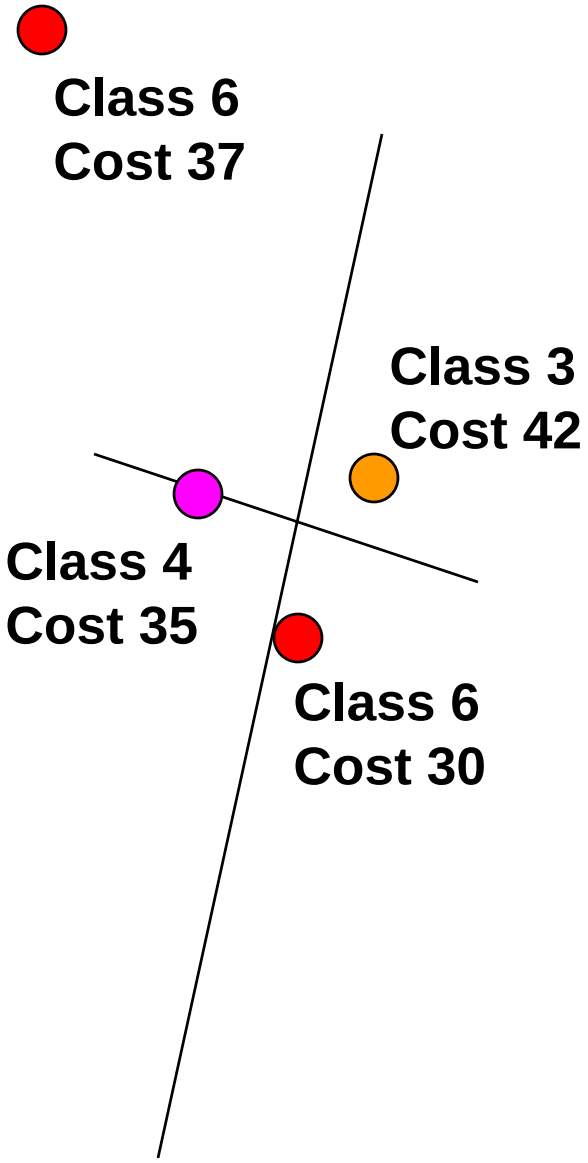
- Values calculated using the Clean Power Estimator
- Each map point represents a city or location where the utility is known



Residential NPV (IL, USA)

WinDS GIS Processing

- GIS serves to prepare data inputs to a linear program
- Available windy land determined using exclusions based on the 1991 PNL windy lands assessment methodology (moderate land use exclusions)
- Assignment of wind resource to available transmission lines (used to generate regional wind supply curves)
- Demand, transmission capacity, load, current generation capacity, and planned retirements allocated to the regions



WinDS GIS Processing: Transmission Assignment

- Each wind cell is assigned a cost based on the power class and distance to transmission
- Transmission line carrying capacity is based on voltage and length
- Wind cells are assigned to transmission lines based on cost, as long as they don't exceed the transmission line's available capacity
- Continues until all wind is assigned or all transmission capacity is used

WinDS GIS Processing: Transmission Assignment (cont.)

- Allows lower power classes onto lines as long as they have the next lowest cost (distance component of cost function)
- All wind records track what transmission line they were assigned to, the cost at which they were assigned, and in what region they are located (used to generate wind supply curves for each region)

Other GIS-Compatible Factors Influencing Wind Site Selection

- Slope (being implemented in WinDS)
- Population Density (being implemented in WinDS)
- Viewshed obstruction
- Property values/property tax rates
- Coincidence with rural economic zones
- Presence of sacred sites, local wildlife areas, avian migration routes, etc.

Recommendations for Future Work

- Update windy land numbers as:
  - Updated state maps are completed by TWS
  - Enough 100 m + resource data becomes available
- Determine offshore potential
  - Need to define exclusion criteria
  - Northeast coast will likely be the first section completed
  - No definite timetable
- See how temporal variability and forecasting can be incorporated into modeling efforts